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STORING SOUTHERN PINE SEED

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This paper gives directions for dry, cold storage of southern pine seed. Such storage, although not infallible, is the best method yet developed for keeping a high percentage of the seed capable of the vigorous germination essential to good results in the nursery.

Dry, cold storage involves refrigerating seed promptly and continuously at a temperature not exceeding 41° F. and preferably between 32° and 5° F., and at a constant moisture content between 6 and 9 percent for longleaf pine and between 9 and 12 percent for other southern pine seeds. The details of the process must, however, be varied to fit local circumstances.

Principles of Successful Storage

Storage problems can best be overcome if three main facts are kept in mind.

1. So long as a seed is alive, it respires. That is, it consumes the plant food stored within it; it uses oxygen; it liberates carbon dioxide, water, and heat. Some respiration is essential to keep the seed alive, but too much rapidly uses up the stored food on which seedling growth depends, and injures the seed in other ways. Keeping respiration just above the minimum safe level is therefore basic to successful seed storage. The rate of respiration increases slowly with increases in storage temperature up to about 41° F., and with increases in seed moisture content up to 10 percent with longleaf pine and to somewhere between 10 and 12 percent with other southern pines. Above these levels, the rate of respiration increases tremendously with increases in temperature and seed moisture content. It also increases tremendously with injury to the seed.

2. Seed is in storage from the time the cone ripens until pregermination treatment or sowing--not just while in containers or buildings specifically set aside for storage purposes. Excessive respiration at any time between ripening and sowing may weaken or kill the seed. For example, many lots of southern pine seed properly refrigerated most of the time between extraction and use have deteriorated badly during brief exposure to adverse conditions before refrigeration or between refrigeration and sowing.

3. Storage succeeds only when all influences that materially affect respiration are kept favorable. These influences include not only storage temperature and seed moisture content, but also the initial soundness and vitality of the seed. Thus correct collection, extraction, and dewinging, and correct drying if special drying is necessary, are the foundations of successful storage. Only if these processes are properly carried out will the seed enter storage with the necessary soundness and vitality.

In the light of these three main facts, successful cold storage narrows down to the following jobs:

Locating a dependable cold storage locker or warehouse. The two main things to consider are the level and maintenance of the temperature and humidity.

Any temperature between 5° and 41° F. is satisfactory, but temperatures between 5° and 32°, although they may injure excessively moist seed, preserve properly dried seed better than do temperatures between 32° and 41°. Prolonged or frequent increases of temperature above 41° make a warehouse unsuitable for seed storage. Occasional brief rises in temperature while defrosting the refrigerator will, however, do no harm to dry seed.

The relative humidity of the air in the refrigerator should preferably be low and constant. If these conditions cannot be met, the seed must be dried before storage and stored in airtight containers, as described later.

Avoiding injury to the seed. The chief causes of injury, other than actual storage at too high temperatures and moisture contents, are:

Letting the cones or the extracted seed heat spontaneously, or mold.

Excessive artificial heat during extraction or drying.

Bruising the seed or cracking or scarifying the seed coats during dewinging or cleaning.

Taking too long to extract or dry the seed, letting the seed lie around too long before drying or storage, or letting dried seed reabsorb moisture before or during storage.

Drying the seed to the right moisture content before or in the earliest part of the storage period.

Care During Collection and Extraction

Seed should not be collected until the cones are fully mature. A simple, reliable test for cone maturity is to pick one sample cone apiece from each of 20 or more standing trees and drop each cone immediately into SAE 20 lubricating oil, or into a mixture of 1 part of kerosene with 4 parts of raw linseed oil. When sound cones from 19 out of 20 trees will float in the oil, the crop is ripe enough for picking. Cones that sink are still immature. The test is unreliable if applied to wormy cones, to cones from trees felled more than a few hours previously, or to cones that have been separated from the tree for more than a few minutes.

Cones may be gathered at any time after they pass the oil test, but the longer collection can be postponed without losing the seed through opening of the cones on the tree, the better the seed is likely to keep in storage.

A wetting right after collection may not harm the cones, but it is safer to protect them from rain. Free circulation of air through the piles or around each sack of cones will prevent heating and reduce not only molding but also shipping weight and the length of time needed for extraction. High or fluctuating seed moisture content (even for very brief periods and especially if accompanied by exposure to moderate or high air temperature) between collection and extraction or storage may prevent successful storage even if it does not immediately reduce germinability.

Cones should not be left in sacks more than a week after collection--ten days at most. Preferably they should be spread in curing sheds or on extracting racks or trays within 3 or 4 days after collection. The importance of such spreading cannot be emphasized too strongly, and the necessary space and equipment should always be provided before collection starts.

For final drying to extract the seed, cones should never be spread in layers more than 2 cones deep, even in air-temperature extraction on wire shelves or trays. In kilns, or in air extraction on tight floors, they should never be spread in layers more than one cone deep. Any apparent saving of space or of investment in equipment made by using deeper layers is false economy. Deeper layers delay drying, prolong the extracting period, and necessitate rehandling that more than offsets the saving in equipment costs. They

often reduce the yield and quality of seed, and may prevent altogether the functioning of certain types of kilns.

Drying cones in kilns

In most of the southern pine region, kiln-drying the cones reduces seed more nearly to the right moisture content for storage than does air-drying. Unlike air-drying, however, kiln-drying involves some danger to the seed from excessive artificial heat. To extract seed without injury, a kiln must circulate the hot air freely and rapidly among all the cones, keep temperature and humidity below levels injurious to the seed, and permit adjustment of temperature and humidity schedules to meet the requirements of different batches of cones[1/].

Air circulation.--Rapid circulation of the air around every cone serves two important purposes. One is to get all the cones dry and open as quickly as possible and at about the same time. The other is to keep the temperature of the seeds safely below that of the air in the kiln while the seeds are still very moist, as they are in unopened cones freshly placed in the kiln. Seeds are most easily injured by high temperature when their moisture content is high. As long as the air moves rapidly, cones and the seeds they contain are cooled by evaporation from the cone surfaces. If the air moves sluggishly, evaporation slows or ceases and the moist cones and seeds become as hot as the kiln air. Then ordinarily safe kiln air temperatures may injure seeds, and slightly higher temperatures may kill them outright.

Temperatures.--As a general rule, longleaf seed should be extracted at a maximum air temperature of 115° F., and shortleaf, loblolly, and slash at a maximum of 120° F. Occasionally longleaf has been extracted at 120° to 130° F., loblolly and slash at 130° F., and shortleaf at 140° F., without excessive injury, but these temperatures are not recommended.

Kiln temperatures are measured as close as possible to the place where the incoming hot air first hits the cones. In a forced-draft kiln this usually is high on the wall opposite the air inlet. In a kiln utilizing upward convection currents it is under the lowest screen. In one utilizing downward convection currents it is above one of the topmost trays. No kiln should be without a direct-reading and preferably also a maximum thermometer at the point described. A

1/. Rietz, R. Kiln design and development of schedules for extracting seed from cones. U. S. Dept. Agr. Tech. Bul. 773, 70 pp., illus. 1941.

recording hygrothermograph at the hottest point is essential to safe, efficient operation of a forced-draft kiln.

Humidity.--The kiln should always be run at the lowest humidity attainable without wasting fuel. This not only safeguards the seed but speeds up cone opening. For an hour or more at the start of a run the humidity cannot be brought as low as it can later. Moderately high humidity is least dangerous at the start of the run, however, because the rapid evaporation which keeps the humidity up also cools the cones and keeps the temperature of the seed many degrees below that of the kiln air. Humidity is decreased mainly by increasing the rate at which the hot air with its load of moisture is allowed to escape from the kiln.

Since seed injury at any temperature is likely to increase with duration of exposure, seed should be removed from the kiln as soon as possible after the cones have opened completely.

Dewinging Seed

Seed keeps better if the wings are left on during storage and removed just before sowing time. Where cold storage space is at a premium, however, or where the seed is to be shipped, dewinging seed of all species except longleaf is usually justified to reduce weight and bulk. Seeds may be dewinged by hand rubbing, by machine, or by wetting the wings.

Hand rubbing is least likely to injure the seed. Though slow, it is frequently the most economical method for small lots, and some operators prefer it even for large lots. Generally, however, mechanical dewingers are an economy wherever large amounts of seed have to be handled.

To operate mechanical dewingers at full capacity without injuring the seed requires great care. The brushes must usually be of fiber instead of wire, and neither too soft to be effective nor so stiff as to crack the seed coats, especially of longleaf. They must be replaced before the bristles become so short as to lose their springiness. Care is also necessary in adjusting revolutions per minute and rate of feed. Sometimes the seed must be dried artificially to facilitate mechanical dewinging. Optimum adjustment and procedure must be determined and maintained for each dewinger and species by trial runs and by frequent close examinations of the seed (preferably with a hand lens), and in some cases by special germination tests.

When the wing of any southern pine seed except longleaf is thoroughly moistened, the two curved prongs which attach the wing to the seed

straighten out within a few seconds and the seed falls away at a touch. Advantage can be taken of this fact by dipping the hands repeatedly in water during dewinging by hand rubbing, or by spreading the seed on screens in layers about an inch deep, hosing it until thoroughly moist, and stirring it repeatedly until dry.

These wetting methods frequently are cheaper than mechanical dewinging of dry seed. Their disadvantage is that they usually increase seed moisture content enough to cause deterioration or spoilage unless special precautions are taken to dry the seed after dewinging.

Drying Seed

For best results, as already mentioned, longleaf seed must be dried to a moisture content of 6 to 9 percent, and seed of other southern pines to a moisture content of 9 to 12 percent. The drying may be done before or during the earliest days of cold storage. Once dried, seed must be maintained at the lowest moisture content reached. The reasons are the excessively rapid respiration of seed at moisture contents above the levels mentioned, and possible injury to the seed from repeated changes in moisture content at any levels.

There are two ways of getting seed dry enough without overdrying it. The more precise way is to dry each seed lot to a certain weight calculated from the weight before drying and from the moisture content percent of carefully drawn samples dried in an electric oven[2/]. An approximate method more suitable for small-scale operations is to expose the seed for several hours or days to some combination of temperature and relative humidity which tests have shown will dry it to the desired level.

The curves in figure 1, although based on a sample of longleaf pine seed, show approximately the moisture contents reached by southern pine seed of any species at the temperatures and humidities shown at the side and bottom, respectively, of the chart.

The chart can be used to check whether any given combination of temperature and humidity within the limits shown will dry seed to the right content. For example, if the temperature of the air

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2/. Wakeley, Philip C. Planting the southern pines. Southern Forest Experiment Station Occasional Paper 122. (Processed.) 579 pp., illus. 1951.

remains at 75° and its relative humidity at 55 percent, the seed will eventually dry to slightly below 10 percent moisture content. If, however, the temperature is 75° and the relative humidity 90 percent, the seed will dry little if any below 16 percent, which is too high for successful storage.

The higher the temperature, the smaller the seed lot, and the drier the seed is at the start, the sooner the seed will come into moisture equilibrium with the air--that is, become as dry as the particular combination of temperature and humidity will ever make it. Lots weighing only a few pounds may dry sufficiently at 75° or 80° F. in a day or less; lots weighing several hundred pounds may take three or four weeks, especially if the temperature is near freezing.

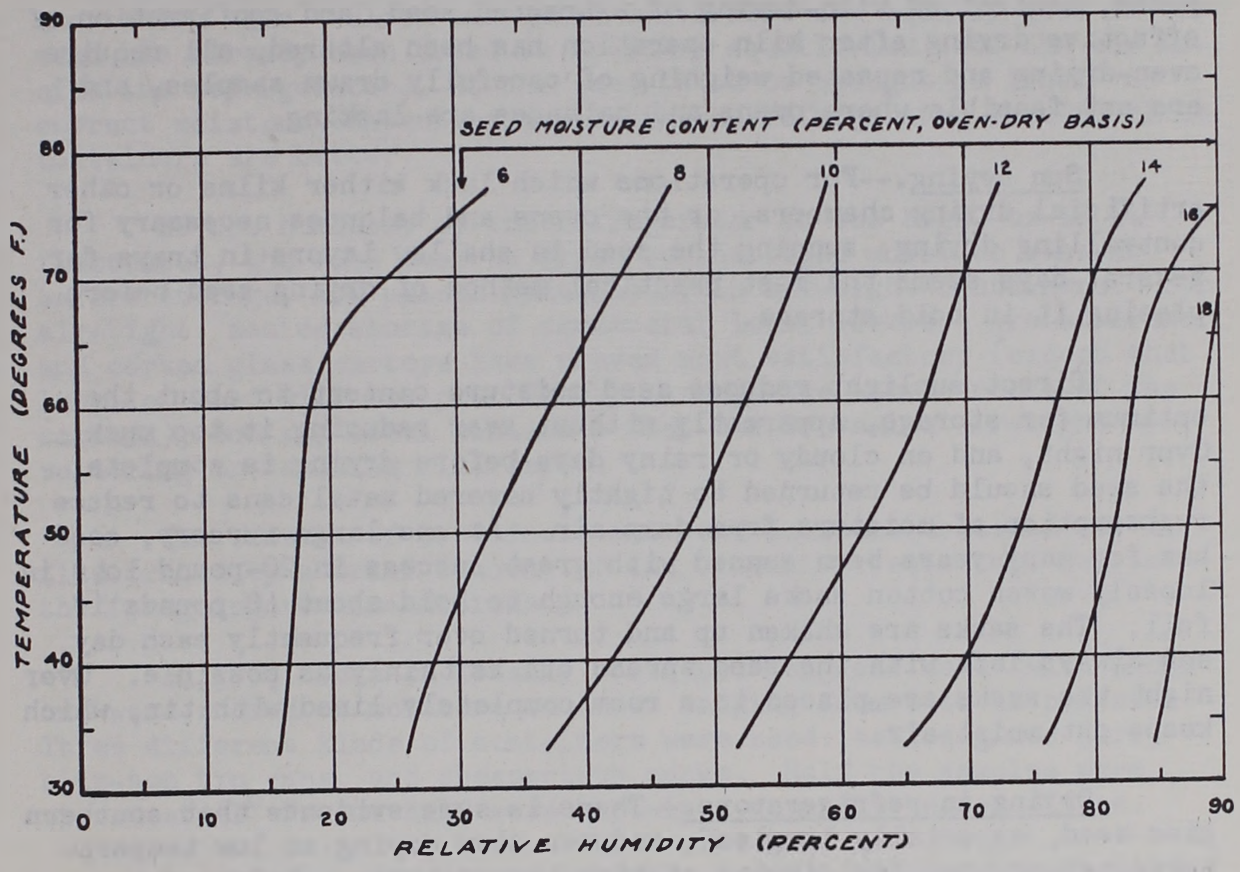

Figure 1.--Moisture content percentages of fresh longleaf pine seed (1938 crop, Mississippi, extracted at air temperature) in equilibrium with air at various temperatures and relative humidities.

Drying by artificial heat.--When seed comes from a cone kiln too moist for storage, it can be dried by placing it in the kiln (in shallow layers in wire trays) for a few hours at temperatures slightly below those recommended for extracting the species concerned. Later batches can be extracted at more nearly correct moisture content by precuring the cones more thoroughly, loading the kiln less heavily, increasing kiln temperature, reducing relative humidity within the kiln, lengthening the kiln run, or substituting "progressive" for "batch" operation of the kiln[2/].

In kiln-drying extracted seed, free movement of air over and among the seeds is essential. Excessive drying at any temperature may injure the seed. Such injury increases with degree or duration of temperature and with the moisture content of the seed when drying starts, and is often intensified by subsequent storage of the seed.

Detection of excessive seed moisture content in the first place, control of kiln-drying of extracted seed, and confirmation of effective drying after kiln operation has been altered, all require oven-drying and repeated weighing of carefully drawn samples, and are not feasible where ovens and balances are lacking.

Sun drying.--For operations which lack either kilns or other artificial drying chambers, or the ovens and balances necessary for controlling drying, sunning the seed in shallow layers in trays for several days seems the most practical method of drying seed before placing it in cold storage.

Direct sunlight reduces seed moisture content to about the optimum for storage, apparently without ever reducing it too much. Over night, and on cloudy or rainy days before drying is complete, the seed should be returned to tightly covered metal cans to reduce reabsorption of moisture from damp air. At one large nursery, seed has for many years been sunned with great success in 20-pound lots in loosely woven cotton sacks large enough to hold about 40 pounds if full. The sacks are shaken up and turned over frequently each day, and always left with the seed spread out as thinly as possible. Over night the sacks are placed in a room completely lined with tin, which keeps out moist air.

Drying in refrigerators.--There is some evidence that southern pine seed, especially longleaf, endures slow drying at low temperatures better than fast drying at high temperatures. Refrigerators operated at 35° F. and 33 percent relative humidity, or at other suitable combinations (fig. 1), effectively reduce the moisture content of southern pine seed in cloth sacks or other containers that allow moisture to escape easily. Seed placed in refrigerators at 13 or 15 percent moisture content and dried in this way to 8 to 10 percent appears to stand storage better than seed dried to the same

level before being refrigerated. Where facilities are available, such refrigeration may be the best way to complete the drying of southern pine seed for storage.

How Containers Affect Storage

Although many confusing statements about the influence of containers on seed storage have been published, the principles are very simple. Containers influence the keeping quality of southern pine seed largely, if not entirely, through their effect on seed moisture content. They should be chosen, therefore, first for their effect on moisture content and second for cheapness and convenience.

If the humidity of the storage locker or warehouse is low (fig. 1) and constant, seed can be stored in burlap or cotton bags, or in metal containers with non-airtight covers, such as garbage or shortening cans. Cloth and metal containers are equally good if the seed has already been dried to moisture equilibrium with the air inside the refrigerator. If the seed is to be brought to final correct moisture content by drying in the refrigerator itself, cloth containers are better.

If the humidity of the refrigerator is too high, or if it fluctuates, the seed must be dried to the right moisture content before storage, and placed immediately in air-tight containers. For air-tight, sealed storage of commercial lots, gasketed grease drums and corked glass carboys have proved most satisfactory (except that longleaf seed will not pour freely through the narrow necks of the carboys), but any metal container that can be sealed air-tight by soldering or caulking will serve.

The effects of containers and seed moisture contents may be illustrated by a brief account of the extensive tests that led to the foregoing recommendations.

In 1937, lots of freshly collected longleaf seed (with wings on) were stored at moisture contents ranging from 6 to 18 percent. Three different kinds of containers were used: sealed glass jars, slip-top tin cans, and cheesecloth sacks. Half the samples were stored at 41° F. and half were kept in a normally heated office.

Results are summarized in table 1. All seed stored at air temperature was dead in two years, and only the lot stored at 6 percent moisture in sealed jars remained viable through the first year. At 41° the seed kept well for 4 years and fairly well for 5 when maintained at 6 or 9 percent moisture by sealed jars. But seed stored in glass at 18 percent moisture deteriorated considerably in

one year and was dead in two, despite refrigeration. In brief, sealed containers, which kept the seed dry, were better than unsealed when the seed was stored at moisture contents below 10 percent. Unsealed containers, because they permitted drying in storage, were better for seed placed in storage at initial moisture contents of 15 and 18 percent.

Table 1.--Five-year storage of 1937 longleaf pine seed at two temperature levels and varying seed moisture contents.

Approximate initial moisture content of seed; storage container	Germination percent at 32 to 38 days						
	Before storage	After air-temperature storage for:		After storage at 41° F. for:			
		1 year	2-5 years	1 yr	2 yrs	4 yrs	5 yrs
6 percent							
Sealed glass jar	77	62	0	88	82	71	47
Slip-top tin can	77	1	0	84	86	52	32
Cheesecloth sack	77	0	0	85	92	60	21
9 percent							
Sealed glass jar	76	1	0	89	92	78	40
Slip-top tin can	76	1	0	88	83	58	14
Cheesecloth sack	76	0	0	82	84	48	28
12 percent							
Sealed glass jar	83	0	0	85	87	32	18
Slip-top tin can	83	1	0	96	84	41	16
Cheesecloth sack	83	1	0	82	76	30	15
15 percent							
Sealed glass jar	83	0	0	69	78	14	13
Slip-top tin can	83	1	0	87	73	41	19
Cheesecloth sack	83	0	0	82	76	42	16
18 percent							
Sealed glass jar	87	0	0	50	0	0	0
Slip-top tin can	87	0	0	86	79	30	5
Cheesecloth sack	87	1	0	77	76	46	21

A test with dewinged slash pine seed gave closely similar results. All lots, even the moistest (18 percent) remained useful after 5 years of refrigeration at 41°, but at air-temperature only dry seed in glass jars lived for 2 years and none stayed alive for 3. Rather surprisingly, the lots originally at 6 and 9 percent moisture content and stored in slip-top tin cans at 41° deteriorated more by the end of the fifth year than did the moister seed in such cans. The explanation is that these lots were below moisture equilibrium with the air of the refrigerator, and the cans permitted the seed to

increase in moisture content during storage. This is a forceful reminder of the danger, previously mentioned, of letting seed moisture content rise or fluctuate during storage.

Slash is less exacting than longleaf in its requirements for long storage, but numerous studies strongly suggest that it be refrigerated at no more than 12 percent moisture content, and at no less than 9 percent for open containers and 6 percent for sealed.

Less is known about requirements for storing shortleaf and loblolly seed, but they clearly resemble those for slash more closely than those for longleaf. Shortleaf seed, like slash, has been stored successfully for 19 years at 35° to 38° and approximately 10 percent moisture content, whereas longleaf has not been kept successfully under these conditions for more than 10 years.

The foregoing recommendations apply to overwinter storage as well as to long-term storage. Tests of storage for 1, 2½, and 3½ months very strongly confirm the findings of the long-term studies in favor of dry, cold storage, with drying during storage as second choice and dry storage at intermediate temperatures (as little as possible above 41°, perhaps in an unheated building) as third choice, even for the short period between seed extraction and spring sowing. Longleaf seed at 22 percent moisture content, stored in sealed glass at temperatures higher than 38° F., was completely dead at the end of 2½ months. These studies also showed that incorrect overwinter storage, in addition to wasting seed and running up costs, may decrease the reliability of germination tests as guides to sowing rates.

Special storage techniques.--Many refinements of storage techniques have been recommended in various publications, but have given inconsistent or harmful results and at best seem unnecessary with southern pine seed if the main principles of dry cold storage are followed closely. These refinements include disinfecting the seed with mercury compounds or formaldehyde before storage, sealing charcoal in the containers with the seed, and sealing the seed in a vacuum.

Delays are Dangerous

More important than minor refinements in storage or even very precise determination of storage temperature and seed moisture is the need for getting the seed into storage promptly and keeping it there until it is sown. When extraction is delayed too long, some seed will die in the cones. The germinability of extracted seed held at air temperature may decrease seriously in 4 to 8 weeks. Even if immediate germinability is not affected, rapid respiration before cold storage depletes the food reserves within the seed.

For these reasons, nurserymen should avoid the common practice of holding seed at air temperature until part of it has been sown in spring. It is much better to put all the seed in cold storage as it is extracted and to withdraw it, as needed, immediately before sowing. A possible alternative, if refrigerator space is at a premium, is to refrigerate immediately all seed to be held a year or more and to keep overwinter at air temperature only the minimum amount likely to be sown the spring after extraction.

Removing the seed from cold storage much before sowing or testing it may do even more harm than holding it at air temperature before it has been sensitized by refrigeration. This has been shown most clearly with longleaf pine, which often deteriorates seriously in two to four weeks, especially if it is at high moisture content, but results with commercial lots of shortleaf, loblolly, and slash seed indicate that no southern pine seed should be removed from cold storage more than a week before sowing or testing.

Deferring removal in this way may be impossible when seed is to be shipped abroad, especially to South America or South Africa, where the sowing season differs by six months from that in the United States. Rather than expose refrigerated seed to possible high temperatures in transit, it is preferable to arrange export well in advance, ship seed immediately after extraction and cleaning, and keep it in cold storage at its destination from receipt until sowing time.

Recommendations

For storage beyond the first spring following extraction.-- Provided seed moisture content can be kept constant after preparation for storage, the seed should:

a. Be collected, extracted, and dewinged (longleaf should be left with wings on) with minimum injury;

b. Be dried to 6 to 9 percent moisture content for longleaf, or 9 to 12 percent moisture content for slash, loblolly, and shortleaf(or brought to these final levels in the refrigerator, as previously noted);

c. Be placed in cold storage within a week or two after extraction, cleaning, and drying;

d. Be stored at a temperature not higher than 41° F., preferably at 5° to 32° F.; and

e. Be removed from cold storage not more than a week before testing or sowing, or before pregermination treatment if such treatment is necessary.

The seed can be maintained at constant low moisture content either by sealing the containers, or by storing it in air-permeable containers in a refrigerator having a constant low relative humidity (fig. 1).

If sealed containers cannot be used and the seed must be stored in a refrigerator too humid to maintain the moisture content at the most favorable level, the seed should be placed in storage at or slightly above the moisture content at which it will come into equilibrium with the air in the refrigerator. Reducing the seed moisture content below this level and letting it rise in storage should be avoided, as should repeated changes in moisture content during storage.

If storage at 41° F. or below is impossible, seed of all species should be kept at 6 percent moisture content in sealed containers at the lowest temperature available.

For overwinter storage only.--Preferably, seed should be stored overwinter precisely as for longer periods; that is, refrigerated at 41° F. or below, at constant moisture content of 6 to 9 percent for longleaf, or 9 to 12 percent for slash, loblolly, and shortleaf, and otherwise as described for long storage.

Second choice, refrigeration at or below 41° F., at constant moisture content not above 15 percent (any species).

Third choice, storage at temperatures as little as possible above 41° F., and at constant moisture content of 6 to 9 percent for longleaf, or 9 to 12 percent for slash, loblolly, and shortleaf.

For shipment abroad, especially to the Southern Hemisphere.--Preferably, ship immediately after extraction and cleaning, in sealed containers, at moisture content of 6 to 9 percent for longleaf, or 9 to 12 percent for slash, loblolly, and shortleaf. Receiver should refrigerate seed at 41° F. or lower, at the same or lower moisture content (the latter will necessitate unsealing the containers) from receipt until use.

Second choice (especially applicable to seed already refrigerated before shipment), ship at moisture content similar to the above, either in refrigerated holds or by air express with instructions to keep as cool as possible. Refrigerate from receipt until use.